To Study the Current Distributions of Electrically Short Dipoles in Magnetized Collisional Plasma via FDTD Simulations

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Abstract: This paper presents the study of current distributions on dipole antenna immersed in warm, magnetized collisional plasma. The PF-FDTD (Plasma Fluid- Finite Difference Time Domain) model is used to model the antenna in warm, collisional and magnetized plasma. Three different types of current distributions (i.e) one-dimensional current distribution(analytical), three-dimensional current distribution(analytical), PDTD model for current distributions (numerical) are compared with each other and results are observed. These comparisons of the analytical and numerical solutions show that numerical solutions have higher resolution in analyzing the current distributions of an antenna then the analytical solutions and also the advantages and disadvantages of these different analysis methods are discussed.

Introduction: The characteristic of an antenna in a free space can be modeled as a capacitance. But as the free space changes to plasma, the natural resonances within the plasma, couple with the antenna and the most basic resonance will be the plasma frequency, these resonances within the plasm will be complex in nature and the difficulty in the measurements starts. After the first observations of electrical impedance of an antenna immersed in plasma observed by Jackson and Kane[1], there has been rapid growth in the study of electrical impedance and current distributions of antenna in plasma.

The PF-FDTD (Plasma Fluid – Finite Difference Time Domain) model, is a Full Wave self-consistent numerical model based on the Yee cell discretization of Maxwell's equation, Ohms Law and the plasma fluid equations[2]. The PF-FDTD model is called a Full model because, it has complete set of Maxwell's equations without any assumptions present unlike the analytical models. This full wave analysis feature of the PF-FDTD model yields a self-consistent solution for an antenna's current distribution. The short dipole antenna will be modeled using PF-FDTD model for different temperature conditions of the plasma and the results will be analyzed accordingly. Temperature has been shown to plays a keen role in the density of electrons. When the temperature in the ionosphere is high, the density of the electrons is high and when the temperature goes down, the density of the electrons also decreases gradually [3]in plasma. This paper explores the temperature characteristic of plasma in collisional and magnetized condition via the PF-FDTD. Balmain's concept of one dimensional triangular current distribution [4] , three dimensional exponential current distribution proposed by Staras[5] and solved by P. Nikitin and C. Swenson [6] and PF-FDTD simulations are compared against each other and analyzed for better scientific understanding.

The Model: For the FDTD model the Maxwellian distributed plasma fluid equations are incorporated to overcome the analytical limitations commonly used to represent the plasma as a dielectric tensor. The governing differential equations are converted to finite difference equations through a central difference approximation.

The first step for all FDTD simulations will be discretizing the equations in space. The plasma particles associated with each Yee cell are treated as a single centralized particle, with the density positioned at the center of the cell. As the Lorentz and other forces act upon the charged particles, the average density and velocity of the particles in the cell are recorded. Once trajectory is known, simulation time is advanced in order to find the new electric and magnetic fields. This process is repeated in a the leap-frog scheme of the PF-FDTD[2].

In the Yee Cell, the temperature effects will be seen only when there is density variation in the cells. The neighboring cells density must be known to simulate the warm plasma using the gradient $n(\nabla P = k_b T \nabla n)$. The warm plasma gradient will be added after the cold plasma $(\nabla P = 0)$ has been added. This pressure tensor equation $n(\nabla P = k_b T \nabla n)$, enables the truncation of fluid equations with ideal gas law, where k_b is the Boltzmann constant. These boundary conditions are included into the set of equations governing the fluid equations of the FDTD model and programmed for a warm, collisional, magnetized plasma.

Simulation: For this analysis, a 1-m dipole antenna is modeled in warm, collisional, magnetized plasma. The temperature, the collisional frequency and the magnetized frequency are independently varied in order to isolate the effects on the antennas current distribution and resulting input impedance. The temperature range of the plasma will be varied from a range of 0K to 500K, while the plasma frequency(density) and the gyro frequency (Magnetic Field) is varied from 1 to 10MHz. The collisional frequency is always taken as the ratio of plasma frequency for the simulations. This process is repeated for several sets of collisional and magnetized values.

The well know upper hybrid parallel resonance and series resonance associated with the gryo frequency are easily identified within all simulation data. It is also documented that collisional variation effect the quality of these resonance structures. The temperature effects are harder to discern and may fall within the margin or error of the simulations for the input impedance.

Result: The simulations for warm, collisional and magnetized plasma are expected to be complex in nature. The simulation measures the current distributions with the help of ampere's integral equation.

Preliminary simulations produce non-standard current distributions that do not the leading analytical methods. Comparison to one-dimensional triangular and three-dimensional exponential current distributions show that the analytical methods are frequency limited in their application, specifically around plasma resonances.

Conclusion: This paper presented two different analysis using the FDTD technique for modelling the antenna. The first analysis was about the current distributions of an antenna immersed in warm, collisional magnetized plasma. The simulations with varied temperatures for collisional and magnetized plasma are expected to show that the current distributions of an antennas are different at different temperatures.

The second analysis of the paper was the comparison of one-dimensional current distribution(analytical), three-dimensional current distribution(analytical), PDTD model for current distributions (numerical). It can be inferred that the numerical model is very accurate and closer to the experimental data then the analytical model. It can also be concluded that the analytical models have lot of limitations when compared to the numerical model. Analytical models can be used only for certain conditions while the numerical model can be used for much larger scope.

References:

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